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Analysis of existing agroforestry practices in Madhupur Sal forest: an assessment based on ecological and economic perspectives

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Abstract: A study was conducted in Madhupur sal forest of Tangail, Bangladesh to identify the suitable agroforestry practices of the area. Considering the ecological aspects of different agroforestry practices 10 sample plots (10 m × 10 m) from each land uses were taken, including natural forest to get a comparative scenario. The study showed that among the different agroforestry practices, Margalef and Shannon-Weiner index values are the maximum for pineapple agroforestry and lower for banana agroforestry, and Evenness index value is the maximum for lemon agroforestry. Determination of tree biomass in different land uses revealed that it is highest (3 078.6 kg/100 m^2) in natural forest followed by pineapple agroforestry, lemon agroforestry and banana agroforestry. Soil pH, moisture content, organic matter, organic carbon, phosphorus and total nitrogen showed statistically significant variation while bulk density, particle density, sulphur and potassium did not show any statistically significant variation among the land uses. Soil fertility status showed that pineapple agroforestry is more fertile than rest of other land uses. The Net Present Value (NPV) indicated that banana agroforestry is financially more profitable than other two systems, while the Benefit-Cost ratio (BCR) is higher in pineapple agroforestry (4.21 in participatory agroforestry and 3.35 in privately managed land). Even though banana agroforestry gives higher NPV, capital required for this practice is much higher. The findings suggest that pineapple agroforestry has a tendency towards becoming ecologically and economically more sound than other two practices as it has better ecological attributes and required comparatively low investment.

Key words: Bangladesh; Sal forest; agroforestry; ecological attributes; profitability

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Introduction

Degradation of natural resources, especially land and forest has become a matter of serious concern because the vast populations of the countries have to rely greatly on these resources for their livelihood (FAO 1999). Deforestation is nothing but a prime cause of soil erosion and land degradation (Barbier 1998). Agroforestry, a land use system featured by growing different species of woody perennials in association with field crops, is a suitable land use system specifically for degraded areas. It helps to control soil erosion, reverse environmental degradation through biological interactions of tree and crops and increase income from farmland (Sanchez 1994; Garity 2004). Being a land-use system, agroforesty has been notably considered as an effective and low cost method as it does help to minimize the process of degradation associated with land cultivation and also for it's retention of the ecosystem (Vergara and Nicomedes 1987). This practice is now recognized widely as an applied science that is instrumental in assuring food security, reducing poverty and enhancing ecosystem resilience at the scale of thousands of smallholder farmers in the tropics (Sharma et al. 2007). During the last three decades, various agroforestry systems have been promoted in developing countries as a means to increase household incomes and to generate environmental benefits that are well suited to poor farmers (Franzel et al. 2004).

Bangladesh was rich in forest resources but with the pace of population explosion rapid degradation takes place in its forest reserves. Bangladesh contains 124 500 ha of inland moist deciduous Sal (*Shorea robusta)* forests, which widely distributed in the districts of Dhaka, Tangail, Mymenshingh, Dinajpur, Rangpur (Alam et al. 2010). In recent time most of the Sal forests are severely disturbed by human activities like illicit felling and encroachment by the local people and *Garo* tribal in the Madhupur area of the Tangail district. In response to this situation different agroforestry systems have been developed both in private and in forest department managed land. These agroforesty systems play pivotal roles in offering multiple alternatives and op-

portunities for farmers with a view to improving farm production and income and also providing productive and protective functions to the ecosystems (Sharma et al. 2007). However, these systems differ from one another in terms of their economic and ecological performances as they have some own benefits and drawbacks.

Despite increasing realization of agroforestry as an environmentally and economically suitable land use (Molua 2005), different land uses exert different levels of costs and benefits to the society through generating positive and negative externalities such as soil erosion and environmental degradation (Pagiola 2001). It is, therefore, important for the policymakers to know which land use systems better serve to improve the livelihood of rural people as well as mitigate adverse environmental effects. Unfortunately the study area is lacking of such kind of research and study. So, this study was carried out with a view to explore ecologically and economically suitable agroforestry practices in the study area.

Materials and methods

The study site

Madhupur Sal forest is situated in the Madhupur upazila (Subdistrict) of Tangail district (Fig. 1). The tract lies between 23º50' to 24°50' North latitude and 89°54' to 90°50' East longitude (Nishat et al. 2002). Madhupur Sal forest covers an area of 17 932.15 ha, comprising four ranges namely Madhupur, Aronkhola, Dokhola and Madhupur National Park (MNP) (Khan 2009). The Madhupur tract consists of pleistocene terraces and recent alluvial floodplain. It occupies the central part of the Ganges-Brahmaputra-Meghna Delta. The soil is compact and hard when dry, but melts with the rainfall and becomes soft and tenacious. The soil all over the Sal forest looks reddish brown in color (Banglapedia 2010).

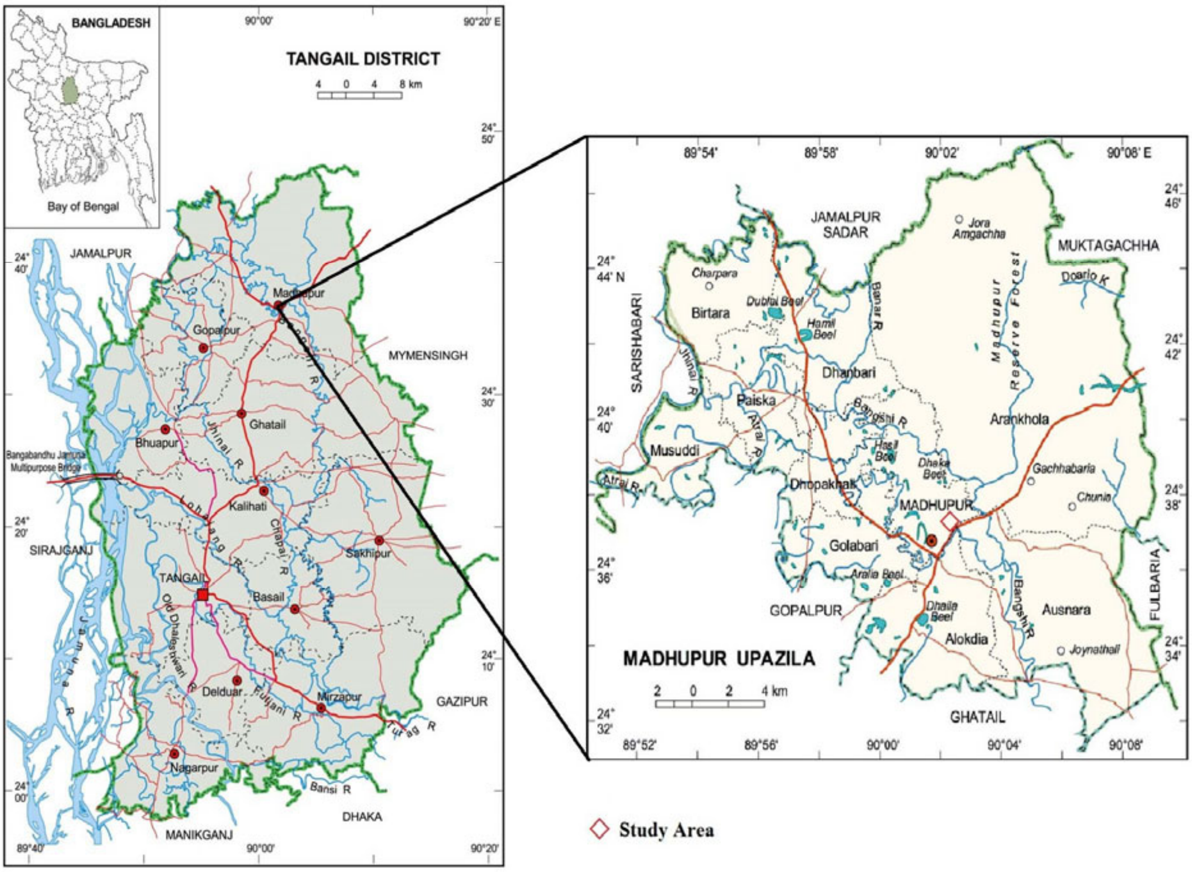

Fig. 1 Map of the study area (Adapted from Banglapedia 2010)

Methods

A total of 30 (10 in each agroforestry practice) plots in different agroforestry land uses and 10 plots (10 m × 10 m) in natural forest were established to collect the soil sample and vegetation survey. From each plot four soil samples of 0−20 cm depth were collected. Then a composite soil sample was prepared by mixing soils from four sites for analysis. Soil sampling for bulk density

measurement was done once for each of 40 plots using a 110.95 cm^3 steel cylinder. For vegetative survey measuring tape, diameter tape and sunto clinometer were used for different measurement. A semi-structured questionnaire was used to gather data regarding respondent's demographic feature, different agroforestry land use information and physical yield data for the productivity and financial analysis. Ten farmers from each agroforestry practices (total three agroforestry practices) were interviewed for data collection.

Estimating floral diversity

Numbers of individuals of each species per plot (10 m × 10 m) were noted to analyze the difference in the composition of the tree species in different land uses. The following indices were calculated as described by Margalef (1958) and Krebs (1985):

$$\text{Margalef Index} = \frac{S-1}{\ln(N)}$$

$$H = -\sum Pi \ln(Pi)$$

$$e = \frac{H}{\ln(S)}$$

where, H=Shannon-Wiener Index, e=evenness index. S is the number of species; n_i is the number of individuals of each species, Pi is the number of individuals of one species divided by total number of individuals in the samples; N is the total number of individuals in the sample.

The higher the Margalef index, the richer would be the species diversity of the population. Evenness refers to the balance between the numbers of individual members of species. The Shannon-Weiner Index is the most commonly used diversity indicator in plant communities, and it takes a value of zero when there is only one species in a community, and a maximum value when all species are present in equal abundance (Mohan 2004).

Estimating woody (tree) biomass

Total biomass was calculated by adding above ground biomass and below ground biomass. Above ground biomass were calculated by following formula as described by Brown et al. (1989).

$$Y = \exp.\{-2.409 + 0.9522 \ln(D^2HS)\}$$

where, exp. = [……] means "raised to the power of […….]", *Y is* the a bove ground biomass in Kg, *H* is the height of the trees in meter, *D* the diameter at breast height (1.3 m) in cm, and *S* is the wood density in units of tonne/m^3.

The model of Brown et al. (1989) was used to estimate the above ground biomass which was reported suitable for estimating above ground biomass by several authors particularly in tropical forests (Mukul 2009). Tree height and diameter at breast height were measured directly at field and a list of wood densities for tropical forests in Asia developed by Brown (1997) was used to estimate above ground biomass. Below ground biomass was calculated considering 15% of the above ground biomass (MacDicken 1997).

Soil properties analysis

Soil moisture content, particle density and bulk density were measured in the laboratory of Department of Forestry and Environmental Science, Shahjalal University of Science and Technology, Sylhet, using standard procedure. The soil chemical and microbial analysis of soil samples were done in the laboratory of Bangladesh Soil Resource Development Institute, Mymensingh, as per following the standard methods.

Elements	Methods
Total nitrogen (%)	Micro Kjeldahl Method
Phosphorous (mg/kg)	Bray and Kurtz' Method
Sulphur (mg/kg)	Turbidimetric Method
Potassium (meq/100 gm soil)	Ammonium Acetate extraction Method
pH	1:2 soil to water ratio suspension by a pH meter
OM (%)	Walkley & Blake Method

Statistical analysis

Analysis of variance (ANOVA) was used to compare the effects of different land uses on different properties of soil. Significant means were separated by DMRT (Duncan Multiple Range Test).

Profitability analysis

Return to land is expressed by net present value (NPV) which determines the present value of net benefits. It was calculated using the following formula:

$$\text{NPV} = \sum_{t=0}^{n} (B_t - C_t)(1+i)^t$$

where B_t is the benefits accrued over the years; C_t, the cost incurred over the years; t, the time period; i, the interest rate.

The benefit-cost ratio (BCR), which indicates the rate of return per unit of cost, was calculated using the following formula:

$$\text{BCR} = \frac{\sum_{t=0}^{n} B_t(1+i)^t}{\sum_{t=0}^{n} C_t(1+i)^t}$$

The BCR greater than 1 indicates that the landuse system is profitable. 10% interest rate was used for the profitability analysis of different agroforestry practices followed by Momen et al. (2006) and Rahman et al. (2007).

Results and discussion

Demographic features of the respondents

Vast tracts of natural forest land of the study area turned into arable land and houses have been constructed. Fruits and vegetables, including pineapple, ginger, lemon, arum and banana are being produced on these lands. Immature sal (*Shorea robusta* Gaertn) timbers from these forests are being cut and sold unabatedly. Besides, lands are being purchased and sold without registration. To protect the remaining forest, back encroach area from encroachers and meet up the rapid need fuelwood, participatory agroforestry has started from 1979 (Hossain 2009). Since then agroforestry became popular land use system in this area. Three types of agroforestry systems were identified in the study area on the basis of their primary product viz. pineapple (*Ananas comosus* (L.) Merr.) agroforestry, lemon (*Citrus lemon* (Linn.) Burm. f.) agroforestry and banana (*Musa* spp.) agroforestry. All the respondents were male. Among the respondents, about 37% belong to ethnic communities, and 60% respondents were literate. Agroforestry were primary income source for 73% respondents.

Table 1 shows the ownership pattern of different agroforestry systems in the study area. Among different agroforestry systems all the ten banana and lemon agroforestry gardens were privately owned, of which there are six gardens for pineapple. The rest of the pineapple agroforestry gardens were managed under participatory basis (Table 1). The participation of ethnic community in participatory agroforestry is less than the Bengali community. Only one ethnic respondent was found, who worked under participatory agroforestry.

Table 1. Ownership pattern of different agroforestry systems in the study area

Type of ownership	Pineapple agroforestry	Lemon agroforestry	Banana agroforestry
Participatory agroforestry	4 (40)	-	-
Privately owned agroforestry	6 (60)	10(100)	10 (100)
Total	10(100)	10(100)	10(100)

Values in the parentheses indicate the percentage; Source: analysis of the field data

Different agroforestry systems in study area

Pineapple agroforestry is one of the most popular agroforestry practices in the study area and it has started roughly since early 1980's. Pineapple is the main product in this system; turmeric (*Curcuma longa* L.), ginger (*Zingiber officinale* Roxc.), papaya (*Carica papaya* Linn.), aurum (*Colocasia esculenta* (L.) Schott) and different types of fruits species such as jackfruit (*Artocarpus heterophyllus*), mango (*Mangifera indica* L.) etc. are raised as secondary crops. Along with these crops a number of fast growing timber species were also planted in this system. The important timber species are akashmoni (*Acacia auriculiformis* Wild.), mangium (*Acacia mangium*), bokain (*Melia sempervirens* (L.) All.) etc. In participatory pineapple agroforestry, forest department provides the seedlings of timber species. Three to four years of production cycle is maintained for pineapple while ten-year rotation is maintained for the system. Pineapple is planted in rows with 1 m distance and timber species are planted with 4 m^2 spacing. Initial weeding is done three times in a year but from the third year, weeding becomes two times per year. A total of two thinnings were practiced during the whole rotation; first thinning in 4th year and second thinning in the 7th year. Fruits of pineapple usually come in the second year after planting. Generally pineapple suckers are planted in the month of September-November. Fruits are collected twice per year (between October-November and April-June).

Lemon agroforestry is another popular agroforestry system in the study area. It has started since early 1990's. Lemon is the main product in this system and turmeric, ginger, papaya, aurum and different types of fruits species such as jackfruit, olive (*Elaeocarpus robustus* Roxb.) etc. are raised as secondary crops. The important timber species are akashmoni *(Acacia auriculiformis),* mangium (*Acacia mangium*), bokain (*Melia sempervirens*), gamar (*Gmelina arborea* Roxb.) etc. Lemon trees are usually planted with 2 m × 2 m spacing and older plants are usually replaced after six to seven years; sometimes it takes more time to replace the plants in healthy condition. Generally fruits were harvested round the year; however, the production is maximum during monsoon. Cultural practices of this agroforestry are almost similar to the pineapple agroforestry but often in case of private managed agroforestry, the thinning is not maintained as per the prescription of the forest department which is also true for other two systems.

The third type of agroforestry system is the banana agroforestry. It has started roughly since 1985-86. Banana cultivation has brought a great economic revolution in the area. It has become an easy means to bring economic solvent within very short time. Forest department does not allow monoculture of banana as it is very harmful to the soil (Hossain 2009). Farmers now also realized the adverse impact of monoculture of banana. In recent times the local residents felt interested to cultivate banana in mixed culture practice. During the study, it was observed that timber (akashmoni, bokain, mangium) and fruit tree such as jackfruit, mango, jam (*Syzigium cumini*) etc. were planted on boundaries in six gardens out of ten gardens. In case of timber species, a 10-year rotation is maintained. However, fruit tree species are maintained for longer periods, which is also true for other two systems under privately owned gardens. Banana fruits are harvested nine to eleven months after planting. In this system cultural practices are more intensive than the other two systems as this system is more susceptible to pest attack.

Vegetative study

Species composition and ecological attributes of different agroforestry systems and natural forest

Table 2 shows the ecological characteristics of 40 sample plots according to their land use type surveyed from the study area. 33

species were identified from the natural forest and 17, 15, 12 species were counted from pineapple agroforestry, lemon agroforestry and banana agroforestry, respectively (Table 2). A total of 22 tree species were found in natural forest while 12 tree species were found in pineapple agroforestry, 10 species in lemon agroforestry and only 6 tree species in banana agroforestry. In pineapple agroforestry, three leguminosae tree species and four fruit tree species were found.

Table 2. Ecological characteristics of different land uses and agroforestry practices in the study area

Attributes	Total no. of observed plant species	Total no. of herb and shrub species	Total no. of tree species	Margalef Index (tree)	Shannon-Weiner Index (tree)	Evenness Index (tree)
Natural forest	33	11	22	4.32	2.33	0.76
Pineapple agroforestry	17	5	12	2.27	2.02	0.81
Lemon agroforestry	15	5	10	2.1	1.94	0.84
Banana agroforestry	12	6	6	1.57	1.23	0.69

Maximum value (4.32) of Margalef index was found in natural forest; the values for pineapple agroforestry, lemon agroforestry and banana agroforestry were 2.27, 2.10 and 1.57, respectively. The higher the Margalef index, the richer would be the species diversity of the population. As expected, natural forest is much richer in species diversity than those of agroforestry practiced in the study area. It may be attributed to the specific species preferences of the farmer for their agroforestry practices. Motiur et al. (2005) found a fairly high species richness index (7.7) in homestead agroforest in northeastern part of Bangladesh. While in Lawacara national park, Mukul (2009) found a very high species richness index 15.1 and 18.5 for lemon and pineapple agroforestry, respectively. Shannon-Weiner Index of different agroforestry practice of the study area varies from 1.23 to 2.33. Pineapple agroforestry got the highest value among different agroforestry practiced in the study area while it is lower in the natural forest (2.33) (Table 2). Gajaseni and Gajaseni (1999) conducted Shannon tests in the homestead agroforestry of Thailand, and found the ranges from 1.9 to 2.7, Kumar et al. (1994) found 1.12 to 3.0 in Kerala, India. The calculated values of evenness indices are almost similar for each category of agroforestry except banana agroforestry (0.69) and ranges from 0.81 to 0.84, which means that there is a balance between the numbers of individual members of species in those agroforstry practices. In the study area among the different agroforestry practices banana agroforestry contained the lowest value of Margalef index and Shannon-Weiner Index. It is due to the lack of interest of the farmer to plant diverse species in their banana agroforestry plot as they get quick return from banana plant.

Tree biomass in different agroforestry systems and in natural forest

Fig. 2 shows the tree biomass allocation in natural forest and in different agroforestry practiced in the study area. Total tree biomass is highest in the natural forest (3 078.6 kg/100 m^2). Among the different agroforestry practices, pineapple agroforstry has the highest value of tree biomass (1 022.4 kg/100 m^2) followed by lemon agroforestry (776.8 kg/100 m^2) and banana agroforestry (135.9 kg/100m^2).

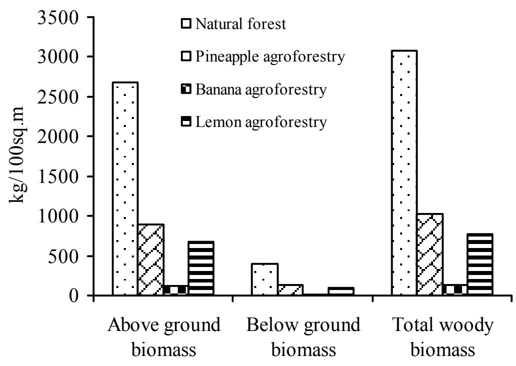

Fig. 2 Tree biomass allocation in different land uses

Soil properties study

The soil pH values of the natural forest, pineapple agroforestry, lemon agroforestry and banana agroforestry varied significantly (statistically) from 4.37 to 5.35. The soil of these sites is strongly acidic (Table 3). The findings were corroborated by Islam and Weil (2000) where the soil pH ranges from 4.9 to 5.6 in tropical deciduous sal forest in Gazipur. Many factors contribute to the naturally very acidic pH levels in these soils, including the pre-weathered parent materials, amphoteric nature of aluminum in these tropical soils and the intense leaching of basic cations during the monsoons, etc (Islam and Weil 2000). The mean value of soil pH was significantly higher in natural forest (5.35) than in lemon agroforestry (5.21), pineapple agroforestry (4.72) and banana agroforestry (4.37) (Table 3). It means that the soil acidity increased with the conversion of natural forest into other land uses. Similar trends were also reported by Chowdhury (2004) and Rahman (2006). Banana agroforestry is significantly more acidic than those of the lemon agroforestry, pineapple agroforestry and natural forest. It may be due to its susceptibility to soil erosion which allowed leaching the base cations. Another reason may be the presence of higher amount of leaf litters in natural, pineapple and lemon agroforestry than the banana agroforestry which have acid neutralization characteristics (Rahman 2006).

Statistically significant variation in moisture content (MC) of different land uses were found in the study area. Pineapple agroforestry contained highest percentage of moisture (20.06%) fol-

lowed by natural forest (19.73%), banana agroforestry (16.31%) and lemon agroforestry (15.59%), respectively (Table 3). There is no significant variation in moisture content between pineapple agroforestry and natural forest, and between banana and lemon agroforestry respectively. But both pineapple agroforestry and natural forest significantly differ from rest of the two. Presence of uniform and higher number of species might be the cause of higher moisture content in the natural forest and pineapple agroforestry. Moisture content was found significantly lower in lemon and banana agroforestry, this may be due to its barren nature or lack of litter cover over the soil for holding the moisture. Chowdhury (2004) found the moisture content in the orange orchard (ranging 17.76 to 20.78%) was significantly higher than natural forest (ranging 12.62 to 16.20%), which was the result of the presence of vegetation having larger height and diameter with thick leaf litter over the surface of plantation in comparison to natural forest comprising mostly young plants with poorly distributed some older trees.

Table 3. Effect of land use types on soil properties in Madhupur sal forest

Land use types	pH	Moisture content (%)	Bulk density (gm/cc)	Particle density (gm/cc)	Organic matter (%)	Organic carbon (%)	K (meq/100g)	S (mg/kg)	P (mg/kg)	N (%)
Pineapple agroforestry	4.72b	20.06a	2.02	2.14	1.67ab	0.97ab	0.28	22.58	18.70b	0.09a
Banana agroforestry	4.37c	16.31b	1.96	2.17	1.50c	0.87b	0.33	18.92	53.42a	0.08ab
Lemon agroforestry	5.21a	15.59b	2.01	2.12	1.56bc	0.90ab	0.25	14.31	8.44b	0.08ab
Natural forest	5.35a	19.73a	1.93	2.16	1.75a	1.01a	0.36	13.50	2.03b	0.07b
Level of sig.	**	**	ns	ns	*	*	ns	ns	**	*

* = Significant at 5% level of probability, ** = Significant at 1% level of probability, ns = Not significant; In a column figures with same letter or without letter do not differ significantly where as figures with dissimilar letter differ significantly as per DMRT.

There was no significant difference in bulk density (BD) value of the four types of land uses. However, natural forest got the lowest bulk density value (1.93 gm/cc) and the highest average value was found in pineapple agroforestry (2.02 gm/cc) followed by lemon agroforestry (2.01 gm/cc) and banana agroforestry (1.96 gm/cc), respectively (Table 3). Similar occurrence was also observed by Islam and Weil (2000) in Gazipur sal forest. They found that soil under cultivation had higher bulk densities than the adjacent soils under well stocked *Shorea robusta*; moreover, they argued that poorer aggregation probably accounts for the higher bulk density. Chowdhury et al. (2007) found that the difference in bulk density in dry soil was larger in orange orchard than forest of Chittagong Hill Tracts, Banglandesh. The existence of lower bulk density in forest soil was also evident from Rolfe and Boggess (1973) as well as Pritchett and Fisher (1987). They explained that the lower soil bulk density may be due to increased burrowing activity of soil fauna and higher organic matter contents. Rolfe and Boggess (1973) found significantly lower bulk density in a pine plantation compared to an old-field soil.

There was no significant variation in the particle density (PD) value between the four types of land uses. In the present study, the mean value of particle density was 2.17 gm/cc in banana agroforestry, 2.16 gm/cc in natural forest, 2.14gm/cc in pineapple agroforestry, and 2.12gm/cc in lemon agroforestry (Table 3). However, Chowdhury et al. (2007) and Rahman (2006) reported that the particle densities decreased with the conversion of natural forest into other land uses.

Statistically significant variation in organic matter (OM) content of different land uses were found in the study area. Natural forest contained highest percentage of organic matter (1.75%) followed by Pineapple agroforestry (1.67%), lemon agroforestry (1.56%), and banana agroforestry (1.50%), respectively (Table 3). The organic matter in natural forest significantly varies from that in lemon agroforestry and banana agroforesty while it did not vary with pineapple agroforesty. On the other hand, pineapple agroforestry significantly varied from banana agroforestry but there was no variation between pineapple and lemon agroforestry, and between lemon and banana agroforestry. Similar result was observed by Mukul (2009) and Chowdhury et al. (2007) where they found organic matter decreased with the conversion of natural forest into another land use. Mukul (2009) found the percentage of organic matter was 2.89%, 1.46%, 1.94% in natural forest, pineapple agroforestry and lemon agroforestry, respectively, at Lawachara national park area.

The organic carbon (OC) values of the natural forest, pineapple agroforestry, lemon agroforestry and banana agroforestry soils varied significantly from 0.87% to 1.01% (Table 4). The mean value of organic carbon was significantly higher in natural forest (1.01%) than in banana agroforestry (0.87) but it was not significantly higher than pineapple agroforestry (0.97%) and lemon agroforestry (0.90%). The findings were corroborated by Islam and Weil (2000) where the organic carbon in natural forest and reforested land was higher than the cultivated soil in tropical deciduous sal forest in Gazipur. The organic carbon in banana agroforestry has significantly less than that in natural forest. Organic matter in cultivated soils has less physical protection than that in the uncultivated soils. Because tillage periodically breaks up macroaggregates and exposes previously protected organic matter in the soil macroaggregates. Thereby increased contact between microorganisms and incorporated plant residues and eventually resulted in faster decomposition of organic matter and loss of organic carbon in the cultivated soil (Nadri et al. 1996). In contrast, the natural forest, pineapple agroforestry and lemon agroforestry have greater input of liable carbon, contributed by the high quality litterfall and root exudates and rapidly

growing legume dominated systems.

There was no significant variation among the mean values of potassium of the four types of land uses. However, the study found that the highest mean value of potassium was found in natural forest (0.36 meq/100 g), followed by banana agroforestry (0.33 meq/100 g), pineapple agroforestry (0.28 meq/100 g) and lemon agroforestry (0.25 meq/100 g), respectively (Table 3). It may be due to the greater input of litter fall and root exudates incase of natural forest. Similar to the potassium content, there was no significant variation among the mean values of sulphur of the four types of land uses. However, the study found that the highest mean value of sulphur was found in pineapple agroforestry (22.58 mg/kg), followed by banana agroforestry (18.92 mg/kg), lemon agroforestry (14.31 mg/kg) and natural forest (13.50 mg/kg) respectively (Table 3). The mean values of phosphorus in the natural forest, pineapple agroforestry, lemon agroforestry and banana agroforestry soils varied significantly from 2.03 mg/kg to 53.42 mg/kg (Table 3). The mean value of phosphorus was significantly higher in banana agroforestry than other three land uses. But there were no significant differences among natural forest, pineapple agroforestry and lemon agroforestry. The reason for the presence of excessive high amount of phosphorus in banana agroforestry may be the excessive fertilizer application in these fields.

Statistically significant variation in total nitrogen of different land uses were found in the study area. Pineapple agroforestry contained highest percentage of total nitrogen (0.09 %) followed by lemon agroforestry (0.08%), banana agroforestry (0.08 %) and natural forest (0.07%), respectively (Table 3). The total nitrogen of pineapple agroforestry significantly varies from natural forest and rest of the two did not vary significantly. The result was corroborated with the findings of Chowdhury (2004) in between Orange orchard and natural forest. This might be due to the abundance of leguminous tree in pineapple agroforestry, which may add higher amount of nitrogen to the soil. However, in natural forest, a mixed nature of the vegetation may lead to increased nitrogen or a decrease in soil nitrogen (Rahman 2006).

Relationship among soil properties

Results show that the soil physical properties responded to the chemical changes of soil resulting from human induced or land cover alterations. There was a considerable degree of correlation within the chemical properties and between physical properties (particle density and organic matter) and the various chemical properties (phosphorus, sulphur, potassium and organic carbon, pH) measured (Table 4). Particle density was significantly positively correlated with potassium content. Moreover, pH possesses highly significant negative correlation with phosphorus and sulphur contents while the sulphur and phosphorus contents are positively correlated. Organic carbon content is positively correlated with nitrogen content. The closest correlation was found between organic carbon and organic matter content. Organic matter content is also positively correlated with nitrogen content.

Table 4. Standardize linear relationship among different soil properties under different land use types in Madhupur sal forest

Standardized variables	P	S	K	pH	OC	OM	PD	BD	MC	N
P	1									
S	0.410**	1								
K	0.084	0.213	1							
P^H	-0.674**	-0.453**	0.036	1						
OC	-0.241	-0.231	-0.013	0.168	1					
OM	-0.256	-0.231	-0.016	0.194	0.998**	1				
PD	0.056	-0.095	0.469**	0.025	0.232	0.225	1			
BD	0.013	0.208	-0.106	-0.114	-0.206	-0.214	0.195	1		
MC	-0.076	0.160	0.138	0.027	0.106	0.110	-0.223	-0.252	1	
N	0.034	-0.253	-0.217	-0.278	0.390*	0.383*	0.193	0.099	0.128	1

* = Significant at 5% level of probability, ** = Significant at 1% level of probability

Soil fertility status

Soil fertility in the study area was evaluated on the basis of soil pH, organic matter content, available total nitrogen, phosphorous, potassium and sulphur. The soil under pineapple agroforestry is more fertile than rest of the three land uses (Table 5). Soils of the natural forest, pineapple agroforestry and lemon agroforestry contain strong acidic pH, while pH in the banana agroforestry is very strong acidic (Table 5). Soil nitrogen content in the pineapple agroforestry is low while it is very low in case of rest of three land uses. Phosphorous, potassium and sulphur contents under pineapple agroforestry system has the optimum values while in banana agroforestry the phosphorous exceeds the very high limit and reaches near the toxic level. Natural forest contain medium organic matter while rest of the three have the low organic matter, in comparison between the three agroforestry, the pineapple agroforestry has the higher values than the lemon and banana agroforestry. Organic matter content not only influences the land productivity but also influences its texture and structure; it helps to reduce leaching of nutrients, increase water holding capacity, supports the activities of microorganisms, improves drainage, reduces erosion and promotes plant hormones (Dahal 1996). Thus the soil fertility in pineapple agroforestry is better than the other agroforestry system in the study area.

Table 5. Soil fertility status under different agroforestry systems and in natural forest*

Land uses	Soil properties					
	pH	Organic matter (%)	Nitrogen content (%)	Phosphorous content (mg/kg)	Potassium content (meq/100g)	Sulphur content (mg/kg)
Natural Forest	5.35 (Strongly acidic)	1.75 (Medium)	0.07 (Very low)	2.03 (Very low)	0.36 (High)	13.5 (Low)
Pineapple agroforestry	4.72 (Strongly acidic)	1.67 (Low)	0.09 (Low)	18.7 (Optimum)	0.28 (Optimum)	22.58 (Optimum)
Lemon agroforestry	5.21 (Strongly acidic)	1.56 (Low)	0.08 (Very low)	8.44 (Low)	0.25 (Medium)	14.31 (Low)
Banana agroforestry	4.37 (Very strongly acidic)	1.50 (Low)	0.08 (Very low)	53.42 (Very high)	0.33 (Optimum)	18.92 (Medium)

*Interpretation was based on the Fertilizer Recommendations Guide of the Bangladesh Agricultural Research Council (BARC 2005).

Profitability of different agroforestry systems

During the study it was found that only three pineapple gardens (two participatory gardens and one private garden), one lemon garden and one banana garden out of 30 have completed their rotation period in the same year and then they were again re-planted. Production data were collected from these gardens. To measure profitability, all costs incurred over a rotation period of 10 years and incomes from the sale of different products were assessed. The BC ratio and NPV are common indicators of financial performance as they take into account both cost and return components. Income generation from these agroforestry systems is continuous and long-term. The costs incurred in agroforestry production are in the form of land preparation cost, labor, maintenance cost (fertilizer, pesticide, weeding etc) and seed/seedling cost. On the other hand, benefits received by farmers include agricultural outputs from pineapple, lemon, banana and other interim agro-crops, prunning materials used and sold as fuel, and from thinning and final harvest.

The financial analysis shows that total compounded cost incurred for cultivation of 1 ha plot under participatory management are Tk 581 748 for pineapple agroforestry. While for privately managed agroforestry total compounded cost are Tk 687 380, Tk 665 555 and Tk 1125 834 for pineapple, lemon and banana agroforestry, respectively (Table 6). On the other hand, from the same piece of land, sum of compounded benefits are Tk 2 300 098, Tk 2 157 694 and Tk 3 461 389 for pineapple, lemon and banana agroforestry respectively under privately managed agroforestry. While it accounts Tk 2 450 370 for pineapple agroforestry under participatory management. In case of some privately owned agroforestry, farmers retain the fruit trees for more years even after the completion of rotation period. From these fruit trees they get some extra benefits. It was calculated that for the retention of fruit trees, annually farmer will get approximately 3.56%, 2.43% and 0.81% of the total benefits in case of privately managed pineapple agroforestry, lemon agroforestry and banana agroforestry, respectively.

The NPV analysis revealed that banana agroforestry is financially more attractive than other two systems while the BC ratio is higher in pineapple agroforestry (4.21 in participatory agroforestry and 3.35 in privately managed land). Despite of higher BC ratio of pineapple agroforestry, farmers in the study area widely practiced the banana agroforestry. It appears that the farmers' decisions regarding what kind of land use they will adopt depends not on the BC ratio, but largely on the net amount of income that they earn or NPV (Cusworth and Franks 1993; Thapa and Weber 1994).

Table 6 Financial performance of different agroforestry practices in the study area

Agroforestry practices		Total cost (compounded)/ Tk	Total revenue (compounded)/ Tk	Net Present Value/ Tk	Benefit-cost ratio
Pineapple agroforestry	Participatory	5,81,748	24,50,370	18,68,622	4.21
	Private	6,87,380	23,00,098	16,12,718	3.35
Lemon agroforestry	Private	6,65,555	21,57,694	14,92,139	3.24
Banana agroforestry	Private	11,25,834	34,61,389	23,35,555	3.07

Profitability of different agroforestry systems under alternative scenarios

Sensitivity analysis is carried out for examining the sensitivity of profitability to different discount rates and change in production cost and financial output. The yields of different components in agroforestry are prone to be adversely affected by natural hazards such as pest attack and storms, and government policies such as trade liberalization and increased supply situations (Rasul and Thapa 2006). In a view what would have happened to the feasibility of the project in such situation, sensitivity analysis (followed by Alam et al. 2010) were done for the following three scenarios:

Scenario A: Cost increased by 20%, while other things remain constant.

Scenario B: Revenue decreased by 15%, while other things remain constant.
Scenario C: Change in interest rate (12%), while other things remain constant.

The results of the analyses (Table 7) show that although profitability of agroforestry systems has been changed considerably in all three scenarios, these are still profitable under each of the situations.

Table 7. Profitability of different agroforestry systems under three alternative scenarios

Agroforestry systems		Scenario A (Cost increased by 20%)		Scenario B (Revenue decreased by 15%)		Scenario C (Change in interest rate 10% to 12%)	
		NPV (Tk)	BCR	NPV (Tk)	BCR	NPV (Tk)	BCR
Lemon agroforestry	Private	13,59,026	2.70	15,91,971	3.81	16,06,143	3.15
Pineapple agroforestry	Participatory	17,52,272	3.51	15,01,066	3.58	19,96,164	4.05
	Private	14,75,241	2.79	17,15,824	3.94	17,35,981	3.25
Banana agroforestry	Private	21,10,387	2.56	18,16,346	2.61	25,67,492	3.06

Conclusion

In the view of the conservation point, the pineapple agroforestry is much more suitable than the other two agroforestry. Soil nutrients under pineapple agroforestry are utilized more efficiently in compare to the banana and lemon agroforestry. Due to excessive use of fertilizer and pesticides in banana agroforestry the quality of soil become worse day by day. Even though banana agroforestry gives higher NPV, capital required for this practice is much higher than rest of the two land uses and thus lead to high degree of risk as the disease and pest infestation is frequent in this system in the study area. In contrast, pineapple agroforestry has the higher BC ratio and this can be increased eventually by proper maintenance of the system. Therefore, it is plausible to advocate for promotion of pineapple based agroforestry as it required comparatively low investment, involved low risk and provide continuous benefits through out the year.

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